

# Searching SUSY Leptonic Partner at the CERN LHC

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## Abstract

Motivated by the observed excess of the di-photon signal in Higgs searches,  $\sigma_{\gamma\gamma}/\sigma_{\text{SM}} \simeq 1.5$ , we argue that models with enhanced  $\Gamma(h \rightarrow \gamma\gamma)$  alone is the most favorable scenario when the latest LHC/Tevatron results are all taken into account. To illustrate this feature, we discuss a scenario within the supersymmetry framework with a light stau that predicts a 125 GeV SM-like Higgs boson. The scenario is consistent with all known constraints, including dark matter production and  $B_s \rightarrow \mu^+\mu^-$ . We focus on the production of stau pairs through  $b\bar{b}$  fusion or gauging pairs. These can significantly enhance the inclusive stau pair rate in comparison with the Drell-Yan process. In our studies, we follow the approach of using hadronic tau-tagging. Taking the most optimistic benchmark point of  $M_A = 600$  GeV and  $M_2 = 125$  GeV, we find it is possible to reach  $5\sigma$  significance for integrated luminosity of  $10 \text{ fb}^{-1}$  at 8 TeV. While for  $\sigma(\tilde{\tau}_1^+ \tilde{\tau}_1^- + X) = 1 \text{ pb}$  at 14 TeV running, it requires at least  $100 \text{ fb}^{-1}$  to reach about  $3.5\sigma$  significance.

## I. INTRODUCTION

The ATLAS and CMS experiments at the CERN Large Hadron Collider (LHC) have both reported a combined  $5\sigma$  discovery of light Higgs boson in the two channels of highest resolution, the di-photon ( $gg \rightarrow h \rightarrow \gamma\gamma$ ) and four-lepton ( $gg \rightarrow h \rightarrow ZZ^* \rightarrow 4\ell$ ) with the data of integrated luminosity of  $5\text{ fb}^{-1}$  at 7 TeV plus  $5\text{ fb}^{-1}$  at 8 TeV running [1]. Both di-photon and four-lepton have shown hints of resonance with reconstructed invariant mass around  $m_{\gamma\gamma} \sim m_{4\ell} \sim 125\text{ GeV}$ . Precision measurement of properties of such resonance will play important role to determine whether it is the standard model (SM) Higgs. Distinct signals of di-photon and four-lepton modes clearly show that there exists a spin zero or spin two resonance that couples to weak gauge bosons. At hadron colliders, the  $s$ -channel resonance can be produced via light quark annihilation or gluon fusion. Since the scalar couples to the left-handed and right-handed fermions, a light quark mass is then proportional to the coupling between this scalar and light quark. If the resonance is a scalar, gluon fusion production becomes the only option. The gluon fusion ( $gg \rightarrow h$ ) production and the di-photon decay  $h \rightarrow \gamma\gamma$  are both loop induced which are sensitive to physics involved in the loops. Measurements of such channels provide ways to probe new physics of higher scale at the same time.

Latest datas from both ATLAS and CMS have shown that the measured di-photon rate is significantly larger than the SM prediction while the four-lepton rate is about the same as the SM prediction at 125 GeV. Results from the CMS collaboration are

$$\frac{\sigma(gg \rightarrow h \rightarrow \gamma\gamma)}{\sigma(gg \rightarrow h_{\text{SM}} \rightarrow \gamma\gamma)} \simeq 1.56 \pm 0.43 \quad (1)$$

where  $h$  is the higgs-like resonance [1]. In the four-lepton channel, the expected SM significance of the SM Higgs is  $3.8\sigma$  while the observed value is  $3.2\sigma$ . The ATLAS collaboration have reported  $4.5\sigma$  significance in di-photon while the SM Higgs expectation is  $2.4\sigma$  and results in four-lepton channel showed an observed  $3.4\sigma$  significance versus a  $2.6\sigma$  expectation. The other channels with  $h \rightarrow b\bar{b}$ ,  $h \rightarrow WW^* \rightarrow \ell\bar{\nu}\ell\nu$  and  $h \rightarrow \tau^+\tau^-$  are more challenging experimentally than the previous two channels. The ATLAS collaboration sees no excess in the above channels while CMS collaboration reported about  $1\sigma$  in the channels. On the other hand, the CDF and  $D\bar{\theta}$  collaborations at Tevatron have both reported excess of  $Wb\bar{b}$  in the light Higgs mass range of 115-130 GeV which is consistent with the LHC findings of 124-126 GeV [2]. The excess at Tevatron is crucial to test various models.

For given scalar mass  $m_h$ , the gluon fusion  $s$ -channel resonance  $h$  production with decaying into diphoton,  $gg \rightarrow h \rightarrow \gamma\gamma$  is proportional to

$$\frac{\Gamma(h \rightarrow gg)\Gamma(h \rightarrow \gamma\gamma)}{\Gamma_{\text{total}}^2(h \rightarrow \text{all})}, \quad (2)$$

thus there only exist three categories to enhance the di-photon: enhanced  $h \rightarrow gg$ , enhanced  $h \rightarrow \gamma\gamma$  or the reduced total width  $\Gamma_{\text{total}}$ . One scenario is through increased  $\Gamma(h \rightarrow gg)$  with total width increasing at slower rate. The second scenario is through increased  $\Gamma(h \rightarrow \gamma\gamma)$ . And the third one is the reduced total width, for instance, the reduced  $\Gamma(h \rightarrow b\bar{b})$  through mixing. Example of the first category is enhanced Yukawa model like Bosonic TechniColor [3] or models with fourth generation fermions[4]. Within SM,  $h \rightarrow \gamma\gamma$  decay involves two types of contribution of  $W$  loop and top quark loop with opposite signs[3]. The SM  $W$ -loop dominates  $h \rightarrow \gamma\gamma$  partial width. The enhancement in  $h \rightarrow gg$  inevitably enhances the cancellation in the  $h \rightarrow \gamma\gamma$ . The enhanced Yukawa model predicts reduced couplings with the weak gauge bosons  $W$  and  $Z$  which leads to significant reduction in the associated production of Higgs  $Wh$  or  $Zh$  with enlarged  $h \rightarrow b\bar{b}$  decay branching fraction. The model with fourth generation fermions predicts similar rate of associated production  $Wh$  as the SM Higgs prediction. However, in order to explain the measurement of  $gg \rightarrow h \rightarrow ZZ^* \rightarrow 4\ell$ , it usually requires significant reduction of all known decay modes in both  $h \rightarrow b\bar{b}$  and  $h \rightarrow ZZ^*$  by introducing new decay channel to fourth generation neutrinos  $h \rightarrow N\bar{N}$ . In the third category, models with reduced total width by reducing  $h \rightarrow b\bar{b}$  and  $h \rightarrow WW^*$  through mixing also predicts suppressed  $Wb\bar{b}$  at Tevatron. Therefore, the over  $2\sigma$  excess at Tevatron of  $Wb\bar{b}$  does not favor the first category or the third category of models. Consequently, models with enhanced  $\Gamma(h \rightarrow \gamma\gamma)$  becomes the most favorable model for combined measurements at both LHC and Tevatron.

In order to achieve the enhanced  $h \rightarrow \gamma\gamma$  without effecting  $gg \rightarrow h$ , the model requires non-colored charged states that couple to the Higgs boson. In the extension of SM, there are several candidates of this kind, for instance,  $W'$ , charged Higgs, heavy leptons or leptonic partners in supersymmetric theory [5]. In this paper, we focus on the light stau in supersymmetric standard models to illustrate models with the enhanced  $h \rightarrow \gamma\gamma$ . In second section, we discuss the benchmark point in MSSM which corresponds to the LHC findings, in particular, the prediction of 125 GeV Higgs that has enhanced  $\gamma\gamma$  rate and predictions consistent with other observations. Furthermore, we discuss the collider phenomenology of the light stau scenario, including the leading productions through other supersymmetric particles. Before we conclude, we use one benchmark

point to discuss its kinematic feature and searching potential at the LHC in the third section.

## II. LIGHT STAUS AND ITS PHENOMENOLOGY

Low energy supersymmetry has been the most elegant solution to the gauge hierarchy problem in the last three decades. In MSSM, the lighter CP even neutral scalar  $h$  behaves as a SM-like Higgs boson and we assume the discovered resonance is the  $h$  boson. The strongest motivation for supersymmetry is the cancellation of quadratic divergence, in particular, the top quark contribution due to large top Yukawa. At the same time, the squarks also significantly modify the Higgs production via gluon fusion and Higgs decaying into di-photon [6]. Since the data set for the four-lepton final states are about the same as the SM Higgs prediction, we argue the gluon fusion production should not be changed significantly by the effects due to squarks.

The general sfermion mass matrix is

$$\mathcal{M}_{\tilde{f}}^2 = \begin{pmatrix} m_{\tilde{f}_L}^2 + m_f^2 + D_L^f & m_f \tilde{A}_f \\ m_f \tilde{A}_f & m_{\tilde{f}_R}^2 + m_f^2 + D_R^f \end{pmatrix} \quad (3)$$

where the off-diagonal entries are  $\tilde{A}_t = A_t - \mu \cot \beta$  for top squark with  $\tan \beta$  the ratio of the vacuum expectation values of the two-Higgs fields which break the electroweak symmetry,  $A_t$  the trilinear squark coupling which breaks the  $R$ -symmetry, and  $\mu$  Higgsino mass parameter, respectively.  $m_{\tilde{f}_L}$  and  $m_{\tilde{f}_R}$  are the left- and right-handed soft-SUSY breaking sfermion masses. The  $D$  terms, in units of  $M_Z^2 \cos 2\beta$  are given in terms of the weak isospin and electric charge of the squark by:  $D_L^f = I_f^3 - e_f \sin^2 \theta_W$  and  $D_R^f = e_f \sin^2 \theta_W$ . The leading contribution is from top squark (stop) and bottom squark in the limit of  $\tan \beta$ . We take  $\tan \beta = 30$  in the following discussion after taking into account the constraint from  $B_s \rightarrow \mu^+ \mu^-$ . So the effect is mostly due to top quark. To calculate the stop effect, one obtains the physical states  $\tilde{t}_1$  and  $\tilde{t}_2$  from the mass matrix in Eq.3. The couplings of the physical squark pairs to the Higgs boson  $h$ , normalized to  $2M_Z^2(\sqrt{2}G_F)^{1/2}$ , are

$$\begin{aligned} g_{h\tilde{f}_1\tilde{f}_1} &= -\cos 2\beta [I_f^3 \cos^2 \theta_{\tilde{f}} - e_f \sin^2 \theta_W \cos 2\theta_{\tilde{f}}] - \frac{m_f^2}{M_Z^2} + \frac{1}{2} \sin 2\theta_{\tilde{f}} \frac{m_f \tilde{A}_f}{M_Z^2} \\ g_{h\tilde{f}_2\tilde{f}_2} &= -\cos 2\beta [I_f^3 \sin^2 \theta_{\tilde{f}} - e_f \sin^2 \theta_W \cos 2\theta_{\tilde{f}}] - \frac{m_f^2}{M_Z^2} - \frac{1}{2} \sin 2\theta_{\tilde{f}} \frac{m_f \tilde{A}_f}{M_Z^2} \end{aligned} \quad (4)$$

The gluon fusion production is proportional to the decay partial width of  $h \rightarrow gg$  which is given

by

$$\Gamma(h \rightarrow gg) = \frac{G_F \alpha_s^2 M_h^3}{64 \sqrt{2} \pi^3} \left| \sum_Q A_Q(\tau_Q) + \sum_{\tilde{Q}} g_{h\tilde{Q}\tilde{Q}} \frac{M_Z^2}{m_{\tilde{Q}}^2} A_{\tilde{Q}}(\tau_{\tilde{Q}}) \right|^2 \quad (5)$$

where the scaling variable  $\tau_i$  is defined as  $\tau_i = M_h^2/4m_i^2$  with  $m_i$  the mass of the loop particle, and amplitudes  $A_i$  are

$$\begin{aligned} A_Q(\tau) &= -2[\tau + (\tau - 1)f(\tau)]/\tau^2 \\ A_{\tilde{Q}}(\tau) &= [\tau - f(\tau)]/\tau^2. \end{aligned} \quad (6)$$

Function  $f(\tau)$  is

$$f(\tau) = \begin{cases} \arcsin^2 \sqrt{\tau} & \tau \leq 1 \\ -\frac{1}{4} \left[ \log \frac{1+\sqrt{1-\tau^{-1}}}{1-\sqrt{1-\tau^{-1}}} - i\pi \right]^2 & \tau > 1 \end{cases} \quad (7)$$

Large  $\tilde{A}_t$  significantly enhances  $g_{h\tilde{t}_1\tilde{t}_1}$ , the coupling of squark pairs to  $h$  which results in large cancellation in the  $\Gamma(h \rightarrow gg)$  for light  $m_{\tilde{t}_1}$  of  $\mathcal{O}(200 \text{ GeV})$  [6]. On the other hand, the  $\tilde{A}_t$  and  $m_{\tilde{t}_1}$  are also constrained by the Higgs mass  $m_h$ .

At tree-level, the mass of  $h$  is bounded as  $m_h^2 \leq m_Z^2 \cos^2 2\beta$  [7, 8]. The dominating loop contribution comes from the top/stop sector. Up to 1-loop precision, the mass of the  $h$  boson is given by the formula [9]:

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \left[ \log \frac{M_{\text{SUSY}}^2}{m_t^2} + \frac{\tilde{A}_t^2}{M_{\text{SUSY}}^2} \left( 1 - \frac{\tilde{A}_t^2}{12M_{\text{SUSY}}^2} \right) \right], \quad (8)$$

where  $m_t = 172.9 \text{ GeV}$  being the top quark mass,  $v = 174 \text{ GeV}$  being EWSB VEV,  $M_{\text{SUSY}}^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$  being the averaged stop mass square<sup>1</sup>. In this paper, we use **FeynHiggs** [11], which has taken account of all the contributions at the two-loop level, to calculate the masses of the Higgs bosons.

To realize a 125 GeV Higgs boson in the MSSM, there have been many successful attempts [10, 12–21]. Generally speaking, loop contributions to  $m_h$  need to be significant. Certain amount of fine-tunings are necessary since the stop masses and the mixing parameter  $\tilde{A}_t$  must be judiciously chosen. In order to have a feeling on the fine-tuning, we have a close look at Eq. 8. At first sight, one can choose  $M_{\text{SUSY}}^2/m_t^2 \gg 1$  in Eq. 8 to enhance the loop contribution. But this set of parameters will result in the split SUSY which relaxes the assumption about naturalness. There is

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<sup>1</sup> The above formula is valid only for small splitting between two stop masses and no thresholds effects [10]. Moreover, Eq. 8 does not include the sbottom and stau contributions, which could be important for large values of  $\tan \beta$ .

another milder way to enhance loop contribution by choosing  $M_{\text{SUSY}}^2/m_t^2 > 1$  and  $\tilde{A}_t^2/M_{\text{SUSY}}^2 > 1$  in Eq. 8. Namely, the stop masses are of order of several hundred GeV to several TeV as well as a large mixing parameter  $\tilde{A}_t$ . In order to minimize the stop effect in the gluon fusion production, we choose large  $m_{\tilde{t}}$  and the relevant input as

$$M_{\tilde{q}} = 1.5 \text{ TeV}, M_{\tilde{u}} = 1.5 \text{ TeV}, M_{\tilde{d}} = 2 \text{ TeV}, A_t = A_b = 2.5 \text{ TeV} . \quad (9)$$

As discussed in the introduction, we focus on the light stau contribution to enhance  $\Gamma(h \rightarrow \gamma\gamma)$  in this paper. Similar to the stop states, large  $A_\tau$  also induces large splitting in the stau mass eigenstates as in Eq. 3. The coupling of stau pair to  $h$  boson is also given in Eq. 4 with

$$\tilde{A}_\tau = A_\tau - \mu \tan \beta \quad (10)$$

Clearly, the contribution of stau to  $h \rightarrow \gamma\gamma$  strongly depends on  $\mu \tan \beta$  [25]. However, A extremely sensitive measurement on  $\tan \beta$  is through  $B_s \rightarrow \mu^+ \mu^-$  and  $B \rightarrow X_s \gamma$ . Recently, LHCb Collaboration have reported a new limit  $\text{Br}(B_s \rightarrow \mu^+ \mu^-) < 4.5 \times 10^{-9}$  [28], which yields a new bound on  $\tan \beta$ .  $\text{Br}(B_s \rightarrow \mu^+ \mu^-)$  is expected to be proportional to  $\tan^6 \beta$  in the MSSM. A SUSY model with a large  $\tan \beta$  is now disfavored by this constraint. Moreover, the Belle measurement on  $b \rightarrow s \gamma$  is  $\text{Br}(B \rightarrow X_s \gamma) = (3.55 \pm 0.24) \times 10^{-4}$  [29]. In this paper, we require that  $|\text{Br}(B \rightarrow X_s \gamma) - 3.55 \times 10^{-4}| < 1.0 \times 10^{-4}$  to constrain the MSSM parameters. In the following discussion, we fix the  $\tan \beta$  value to be 30 and tune the parameter to a larger  $\mu$ -term to enhance the stau effects in the  $h \rightarrow \gamma\gamma$ . We choose the SUSY input as

$$M_{\tilde{\tau}_L} = M_{\tilde{\tau}_R} = 350 \text{ GeV}, A_\tau = 2.5 \text{ TeV}, \mu = 2.15 \text{ TeV}, \tan \beta = 30 , \quad (11)$$

which results in

$$m_{\tilde{\tau}_1} \simeq 120 \text{ GeV}. \quad (12)$$

Slepton searches at the hadron collider have been very challenging. The Drell-Yan(DY) production of light stau pair is only at  $\mathcal{O}(10 \text{ fb})$  for extremely light stau as  $m_{\tilde{\tau}_1} = 120 \text{ GeV}$ . However, in supersymmetric models, direct stau pair production is dominated by the bottom fusion

$$b\bar{b} \rightarrow h, H, A \rightarrow \tilde{\tau}_1^+ \tilde{\tau}_1^-, \quad (13)$$

while the  $gg \rightarrow \tilde{\tau}_1^+ \tilde{\tau}_1^-$  is sub-leading [26]. Figure 1 shows the production of direct stau pair including DY and the  $b\bar{b}$  fusion. The solid line shows the resonant effect in the low  $M_A$  region.

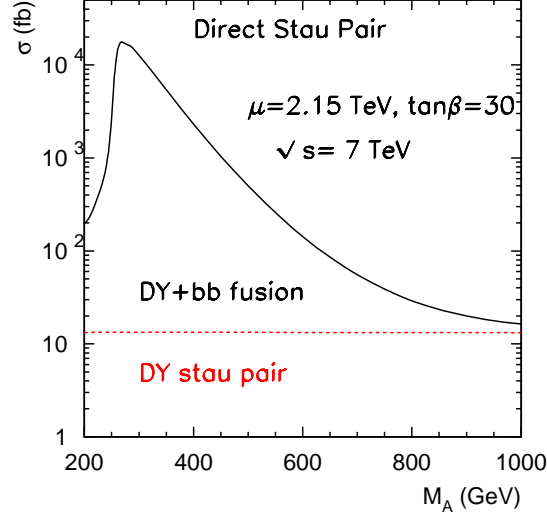


FIG. 1. Direct stau pair production at 7 TeV LHC, DY production plus  $b\bar{b}$  fusion.

On the other hand,  $M_A$  is also constrained by supersymmetric contribution to  $B_s \rightarrow \mu^+\mu^-$  and  $b \rightarrow s\gamma$ . For fixed  $\tan\beta = 30$ , we find

$$M_A > 600 \text{ GeV}. \quad (14)$$

Then the largest possible rate of direct stau pair production for fixed  $\tan\beta$  and  $\mu$  is about 100 fb.

With conserved R-parity, the thermal relic abundance of the lightest neutralino (LSP) can often be identified with cosmic dark matter, consistent with the current cosmological observations  $\Omega_{\text{DM}}h^2 = 0.1120 \pm 0.0056$  [27]. Pure bino is a SM singlet and its annihilation through  $t$ -channel scalar is an important channel. In the light stau scenarios, bino can annihilate into tau pairs  $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tau^+\tau^-$ . To reproduce the required thermal relic abundance, we use MicrOMEGAs [32] and find

$$M_1 = 85 \text{ GeV}, M_2 > 125 \text{ GeV}. \quad (15)$$

In addition, we also checked the other constraints such as muon anomalous magnetic moment. The discrepancy between experiments and the SM calculation is  $a_\mu^{\text{EXP}} - a_\mu^{\text{SM}} = (25.5 \pm 8.2) \times 10^{-10}$  [30]. In this paper, we require that the SUSY contribution to g-2 should be smaller than this deviation. Constraint from EWSB, such as  $\Delta\rho^{\text{SUSY}} < 10^{-3}$  [31] is also included.

Since the lightest stau  $\tilde{\tau}_1^\pm$  is the next-to-lightest supersymmetric particle (NLSP), all other supersymmetric particles can cascade decay into the on-shell stau  $\tilde{\tau}_1^\pm$  final states if the phase space

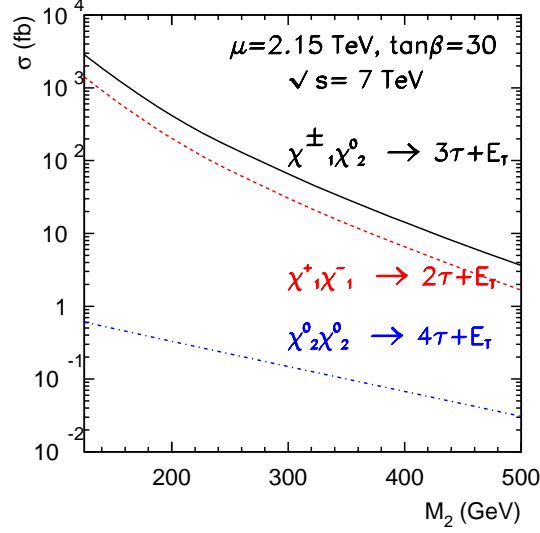


FIG. 2. Gaugino Production Rate with  $\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_1^\pm \nu_\tau$  and  $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^\pm \tau^\mp$

allows. When the two body modes dominate the gaugino decays,

$$\text{Br}(\tilde{\chi}_1^- \rightarrow \tilde{\tau}_1^- \bar{\nu}_\tau) = 100\%, \text{Br}(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^\pm \tau^\mp) = 100\% \quad (16)$$

with 50% of  $\tilde{\chi}_2^0$  decay into  $\tau^+$  and the other 50% to  $\tau^-$ . The gaugino pairs completely turn into multi-stau final states as

$$pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^\pm \tilde{\tau}_1^\mp \tau^\pm \nu_\tau; \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\tau}_1^+ \tilde{\tau}_1^- \nu_\tau \bar{\nu}_\tau, \quad (17)$$

and generate the multi-tau final states plus large missing transverse energy  $\cancel{E}_T$ . In the limit when  $M_2 \rightarrow 125$  GeV,  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  are nearly degenerate with  $\tilde{\tau}_1^\pm$ . The additional  $\tau^\pm$  associated with the  $\tilde{\tau}_1^\pm$  then becomes extremely soft and cannot pass the basic detector cuts. Therefore, the final states are indistinguishable from the stau pair production final states. One particular interesting final state is when

$$pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^\pm \tilde{\tau}_1^\pm \tau^\mp \nu_\tau, \quad (18)$$

which may fall into the same-sign di-lepton plus large  $\cancel{E}_T$  search. In Fig. 3, we plot the production rate for gaugino pairs for varying  $M_2$ . For small  $M_2$ , the production is one order higher than the direct stau pair production with  $M_A = 600$  GeV and completely dominates the stau pair final states.



Finally, we summarize the benchmark scenario as

$$\begin{aligned}
M_1 &= 85 \text{ GeV}, M_2 = 125 \text{ GeV}, M_3 = 1.2 \text{ TeV}, \\
\tan \beta &= 30, \mu = 2.15 \text{ TeV}, M_A = 600 \text{ TeV} \\
M_{\tilde{Q}_L^{1,2,3}} &= M_{\tilde{u}_R^{1,2,3}} = 1.5 \text{ TeV}, M_{\tilde{d}_R^{1,2,3}} = 2 \text{ TeV} \\
M_{\tilde{\ell}_L^{1,2}} &= 1.5 \text{ TeV}, M_{\tilde{e}_R^{1,2}} = 2 \text{ TeV} \\
A_t &= A_b = A_\tau = 2.5 \text{ TeV}, M_{\tilde{\tau}_{L,R}} = 350 \text{ GeV}
\end{aligned} \tag{19}$$

which predicts the MSSM spectrum as

$$m_h = 124.05 \text{ GeV}, m_{\tilde{\tau}_1} = 120.0 \text{ GeV}, m_{\tilde{\chi}_1^0} = 84.91 \text{ GeV} . \tag{20}$$

The predictions of di-photon, four-lepton and  $b\bar{b}$  channels are

$$\frac{\sigma(gg \rightarrow h \rightarrow \gamma\gamma)}{\sigma_{SM}} = 1.52, \frac{\sigma(gg \rightarrow h \rightarrow ZZ^*)}{\sigma_{SM}} = 1.04, \frac{\sigma(Wh \rightarrow b\bar{b})}{\sigma_{SM}} = 0.92 \tag{21}$$

where  $\sigma_{SM}$  is the corresponding predictions of the SM Higgs boson.

### III. SEARCHING STAUS AT THE LHC

At Hadron Colliders, light stau pair can be directly produced via Drell-Yan,  $b\bar{b}$  fusion and gluon fusion. It turns out that the  $b\bar{b}$  fusion is the leading production for  $M_A$  of a few hundreds GeV. Shown in Fig.1, at the benchmark point with  $M_A = 600 \text{ GeV}$ , the Drell-Yan plus  $b\bar{b}$  fusion production rate at 7 TeV LHC is about 100 fb. In addition, as we argued, stau pair from gaugino pair productions can be much larger than the direct stau production. In the limit of  $M_2 = 125 \text{ GeV}$ , stau pair from  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  and  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  are over 3 pb which completely dominates the stau pair production. The stau  $\tilde{\tau}_1^\pm$  further decays into  $\tau^\pm$  and the dark matter candidate  $\tilde{\chi}_1^0$  with

$$\text{Br}(\tilde{\tau}_1^\pm \rightarrow \tau^\pm \tilde{\chi}_1^0) = 100\% . \tag{22}$$

$\tau^\pm$  final states have been playing important role is searching neutral Higgs or charged Higgs Bosons. The pure leptonic  $\tau^\pm$  decay is

$$\text{Br}(\tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau) \simeq 35\%, \ell = e, \mu . \tag{23}$$

From detector perspective, the leptonic final states due to  $\tau^\pm$  are indistinguishable from the direct lepton states. The searches of leptonic taus then fall into the category of pure lepton searches. As

mentioned, 50% of  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  contribute to the same-sign stau pairs  $\tilde{\tau}_1^\pm \tilde{\tau}_1^\pm$ . Therefore, cross-section for same-sign di-lepton plus  $\cancel{E}_T$  final states is

$$\sigma(\ell^\pm \ell^\pm + \cancel{E}_T + X) = 50\% \times 35\%^2 \times \sigma(\tilde{\chi}_1^\pm \tilde{\chi}_2^0). \quad (24)$$

On the other hand, leptons are from the  $\tau^\pm$  three-body decay while  $\tau^\pm$  from  $\tilde{\tau}_1^\pm$  are not highly boosted given the mass difference is only

$$\Delta m = m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} \simeq 35 \text{ GeV}. \quad (25)$$

The leptons in this cascades are typically soft but the search of the same-sign di-lepton usually requires

$$p_T^\ell > 20 \text{ GeV}, \quad (26)$$

which will cut significant part of the leptonic events and we leave this for further studies.

In this paper, we focus on searching  $\tau^\pm$  through the hadronic  $\tau$ -tagging. Without losing generality, we estimated hadronic  $\tau$ 's identification rate and the corresponding jet rejection rate following the performance presented in [34]:

$$\begin{aligned} \eta_\tau &= 60\%, R_j = 5\% \\ \eta_\tau &= 24\%, R_j = 1\% \end{aligned} \quad (27)$$

The rejection rate  $R_j$  corresponds to the faking rate of quark jet or gluon jet being misidentified as a  $\tau$ -jet.

To illustrate the searching strategy, we use the 14 TeV LHC. In principle, for the minimal  $M_2$  and  $M_A$ , 8 TeV machine with  $20 \text{ fb}^{-1}$  data is possible.

We propose two searching mono-jet plus stau pairs ( $j + \tilde{\tau}_1^+ \tilde{\tau}_1^-$ ). The selection cuts are designed as

- the hardest jet with  $p_T > 80 \text{ GeV}$
- $\cancel{E}_T > 50 \text{ GeV}$
- identification of at least two  $\tau$  (reconstructed  $p_T^\tau > 25 \text{ GeV}$ )
- $M_T > 80 \text{ GeV}$  ( $M_T$  defined by minimum  $\Delta\phi$  between  $\vec{p}_T^\tau$  and  $\vec{\cancel{E}}_T$ )

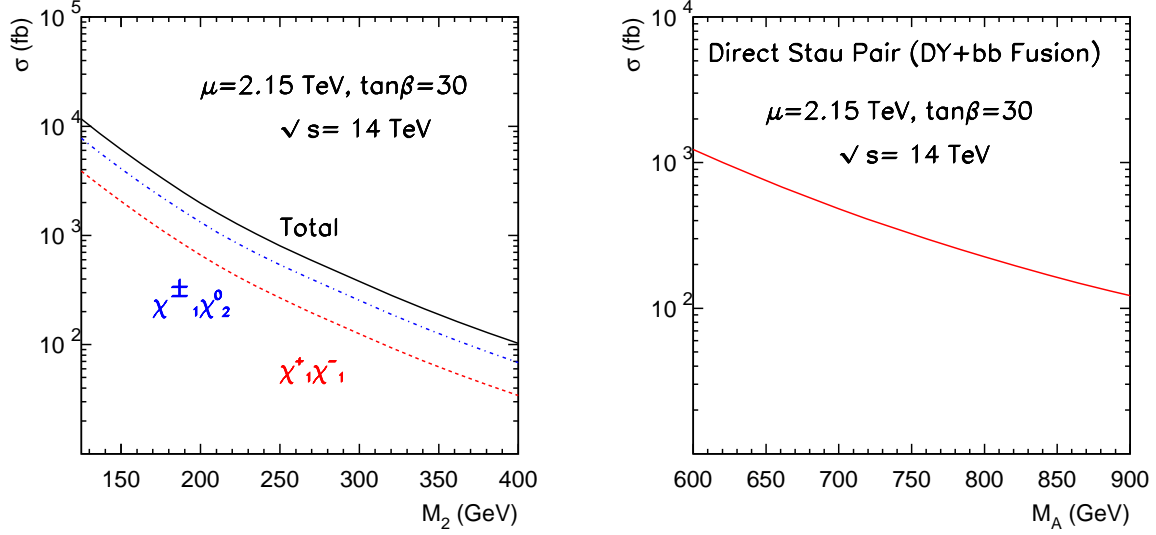


FIG. 3. (a) Gaugino pair production  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  (b) Direct stau pair including Drell-Yan and  $b\bar{b}$  fusion

	signal	$j + \tau^+ \tau^- + \cancel{E}_T$	$2j + \tau^\pm + \cancel{E}_T$	$3j + \cancel{E}_T$
$\sigma(\text{pb})$		0.34	1280	670
$p_T^j \geq 80$ GeV	35.12%	29.67%	20.53%	42.02%
$\cancel{E}_T \geq 50$ GeV	65.24%	53.36%	33.33%	58.82%
$N_\tau \geq 2$ ( $\eta_\tau = 60\%/24\%$ )	11.44%/1.83%	10.14%/1.62%	1.29%/0.102%	0.223%/0.0089%
$M_T \geq 80$ GeV	23.39%	16.27%	4.84%	42.70%
$\sigma_{\text{cut}}(\text{fb})$		0.89/0.14	54.68/4.32	157.68/6.29

TABLE I. Cut efficiency for signal and background.

The backgrounds in Table III are estimated by irreducible background of  $j + \tau^+ \tau^- + \cancel{E}_T$  and the case where one jet or two jets were misidentified as  $\tau$ -jet using the above jet rejection rate  $R_j$ . The reducible background of one jet being faked as tau turns out to be the largest background to start with. With one  $\tau^\pm$  and  $\cancel{E}_T$  in the final states, the leading reducible background is  $Wj \rightarrow \tau\nu + j$  that was misidentified as  $\tau^+ \tau^-$ . To suppress such background, we require the system transverse mass  $M_T$  to be larger than  $m_W = 80$  GeV. Since there were two  $\tau$  in the final states,  $M_T$  is defined by requiring the  $\Delta\phi$  between the  $\vec{p}_T^\tau$  and  $\vec{\cancel{E}}_T$  is the minimal one.

The cut efficiency for the signal is

$$\mathcal{F} = 0.61\% \text{ for } \eta_\tau = 60\%; 0.10\% \text{ for } \eta_\tau = 24\%. \quad (28)$$

One can simply estimate the discovery potential by scaling the production cross section of inclusive stau pairs. In addition, the estimated  $\tau$  trigger efficiency is taken to be 70% that is multiplied to both signal and background. For  $M_A = 600$  GeV,  $M_2 = 125$  GeV,  $\sigma(\tilde{\tau}_1^+ \tilde{\tau}_1^- + X) = 12.88$  pb. Using  $\eta_\tau = 24\%$ , the signal is 9.01 fb while the background is 7.525 fb. For  $10 \text{ fb}^{-1}$ , it reaches a significance of  $7 \sigma$ . For  $\sigma(\tilde{\tau}_1^+ \tilde{\tau}_1^- + X) = 1$  pb and a larger tau-identification rate  $\eta_\tau = 60\%$ , the signal is 4.27 fb and the background is 149.27 fb. With  $100 \text{ fb}^{-1}$ , we find a significance of  $3.5 \sigma$ .

#### IV. CONCLUSIONS

In order to explain the enhanced excess of the di-photon signal in Higgs search,  $\sigma_{\gamma\gamma}/\sigma_{\text{SM}} \simeq 1.5$ , we argue that the models with enhanced  $\Gamma(h \rightarrow \gamma\gamma)$  alone is the most favorable scenario when combining the latest LHC and the Tevatron results. To illustrate this feature, we discuss a scenario within supersymmetry framework with light stau that predicts a 125 GeV SM-like Higgs boson and is in consistent with all the constraints including dark matter and  $B_s \rightarrow \mu^+ \mu^-$  etc. We focus on the production of stau pairs through  $b\bar{b}$  fusion or gaugino pairs which can significantly enhance the inclusive stau pair rate in comparison with the Drell-Yan process. In the studies, we follow the approach using hadronic tau-tagging. Taking the most optimistic benchmark point of  $M_A = 600$  GeV and  $M_2 = 125$  GeV, we find it is possible to reach  $5 \sigma$  significance for integrated luminosity of  $10 \text{ fb}^{-1}$  at 8 TeV. While for  $\sigma(\tilde{\tau}_1^+ \tilde{\tau}_1^- + X) = 1$  pb at 14 TeV running, it requires at least  $100 \text{ fb}^{-1}$  to reach about  $3.5 \sigma$  significance.

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